# Impervious Surface Cover Change in the Lower Mekong Region from Daytime and Nighttime Satellite Data (2001-2012)

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# Abstract

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Impervious surface area (ISA), which is defined as the human-made surfaces that water cannot infiltrate into the soil, is an important indicator of urbanization as well as environmental quality in a drainage basin. Frequent updates of the amount and spatial distribution of ISA can help us understand the human-nature interaction and adverse impacts of ISA on the environment. This information has become increasingly useful for policy-makers, environmental managers and scientists. Although over the past three decades satellite data have been widely used to estimate ISA, it is still a challenge to estimate ISA at a large/regional spatial scale. There remain limitations in the previous methods considering image processing time, cost and ability to quickly map and update ISA. Thus, the objectives of this research are: 1) to develop an easily implemented method for estimating ISA on a large scale using Moderate Resolution Imaging Spectroradiometer (MODIS) and improved Defense Meteorological Satellite Program's Operational Line-scan (DMSP-OLS) nighttime light data (NTL); and 2) to evaluate the applicability of the developed method for estimating ISA in the lower Mekong region from 2001 to 2012 and analyze ISA changes and its impacts on drainage basin health.

A method for estimating ISA for the lower Mekong region was developed by using MODIS and improved DMSP-OLS NTL data. The method involved four major steps. First, a non-vegetation fraction map was generated from time-series MODIS Normalized Difference Vegetation Index (NDVI) data using temporal mixture analysis (TMA). The non-vegetation contains ISA and bare land because both land cover types have similar NDVI temporal profiles. Second, the enhanced-vegetation-index-adjusted nighttime light index (EANTLI) was used to overcome the saturation and blooming effects in the DMSP-OLS nighttime light data. Third, the

relationship between ISA% and EANTLI was derived based on a statistical analysis of the non-vegetation fraction image and the EANTLI image to obtain a preliminary ISA% map. There were two relationships found between ISA% and EANTLI in the study area: the natural logarithmic function is suitable for ISA% values between 0% and 50%; and the quadratic polynomial function should be used for ISA% values greater than 50%. Fourth, the final ISA% map was obtained by selecting smaller values from the preliminary ISA% map and non-vegetation fraction map for each pixel. This is because the non-vegetation land cover contains both ISA and bare land, and thus the ISA% should not exceed the fraction of non-vegetation. The validation results for 2001 showed that the proposed method has promising accuracy, with a root mean square error (RMSE) value of 0.111, a systematic error (SE) value of 0.061, and a determination coefficient of 0.87. The key element of the method lies in building relationships between ISA% and EANTLI. To build the relationship, previous studies generally selected calibration area and used Landsat or high spatial resolution images to generate reference ISA. It can be considered choosing the calibration area to represent the whole region is problematic and that generating reference ISA data for a large scale study is labor-intensive and time-consuming, making it difficult to update the ISA maps. The proposed method just used MODIS and DMSP-OLS nighttime light data, so it is relatively simple and easy to implement.

The proposed method was then applied to MODIS and DMSP-OLS NTL data to produce the annual ISA% maps from 2001 to 2012 and to detect ISA change in the lower Mekong region. In this application, the comparability and consistency of the time-series DMSP-OLS NTL data, which are the inputs in the fourth step of the developed method, need to be taken into account. The raw DMSP-OLS NTL images were captured from different satellites at different years. These data are incomparable and cannot be directly used for change analysis due to lack of on-board calibration in the OLS sensors, sensor degradation, satellite shift and atmospheric effects. To address this issue, inter-calibration of the time-series DMSP-OLS NTL images was carried out using a stepwise calibration method. In addition, further temporal correction was implemented to

the inter-calibrated NTL images by using an assumption that NTL detected in the previous year would not disappear in the later years. In estimating annual ISA, the two relationships (natural logarithmic and second order polynomial functions) between ISA% and EANTLI were found in all the years. The resulted ISA% maps from 2001 to 2012 were used to assess ISA change in the lower Mekong region as a whole and for each country. The regional ISA increased significantly from 29,398 $km^2$ (1.7% of the total land area) in 2001 to 47,635 $km^2$ (2.8%) in 2012, indicating large urban expansion over the period. An increasing trend was observed in the whole study area and each country ($R^2$>0.67). The average annual growths of ISA were estimated at 56 $km^2$/year, 89 $km^2$/year, 442 $km^2$/year and 829 $km^2$/year for Laos, Cambodia, Vietnam and Thailand respectively. Overall, the ISA increase was at an alarming rate that would cause concern about its effects on the environment.

The impacts of ISA on the drainage basins' health in the region were identified based on the percentage of ISA in each basin. Of a total of 847 drainage basins, there were 524 (61.9%) in no_impact category, 280 (33.1%) in stressed category, 40 (4.7%) in impacted category and 3 (0.4%) in degraded category in 2001. The number of basins within stressed, impacted and degraded increased category to 372 (43.9%), 57 (6.7%) and 7 (0.8%) respectively in 2012. In contrast, the number of drainage basins in no_impact category decreased from 524 (61.9%) in 2001 to 411 (48.5%) in 2012. ISA at both the region and the country levels is on an increasing trend due to development pressure, suggesting that there is an urgent need to take appropriate measures to control ISA growth to protect the basins' quality in the region.

Keywords: Impervious surface area, temporal mixture analysis, MODIS, DMSP-OLS nighttime light, EANTLI, drainage basin quality.